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In-Process Testing for Cryo-Figuring 1.5 meter Diameter Auto-Collimating Flats

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14. ABSTRACT

Three auto-collimating flats (ACFs) of 1.5 meter clear aperture are being manufactured for use in the JSC Cryo-Optical Metrology test of the James Webb Space Telescope. In-process interferometric testing of the ACFs is used to guide their surface-figure processing. The surface measurement is performed in a vacuum chamber at both room (+20 °C) and cryogenic (-240 °C) temperatures. With a 12-inch beam diameter FizCam interferometer, sub-aperture measurements are taken across the ACF diameter at multiple rotations. These measurements are stitched together to compute the surface figure. The figure change between room-temperature and cryogenic temperature is measured and used to enable cryo-figuring based on room-temperature measurements. The data analysis is calibrated to account for gravity sag on test-set optics and surface aberrations caused by vacuum pressure and temperature gradients on vacuum-chamber windows. The completed ACFs will have a surface error of less than 75 nm RMS.

15. SUBJECT TERMS

Interferometry, Auto-Collimating Flats (ACF), Cryogenic, Vacuum, Stitching

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Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

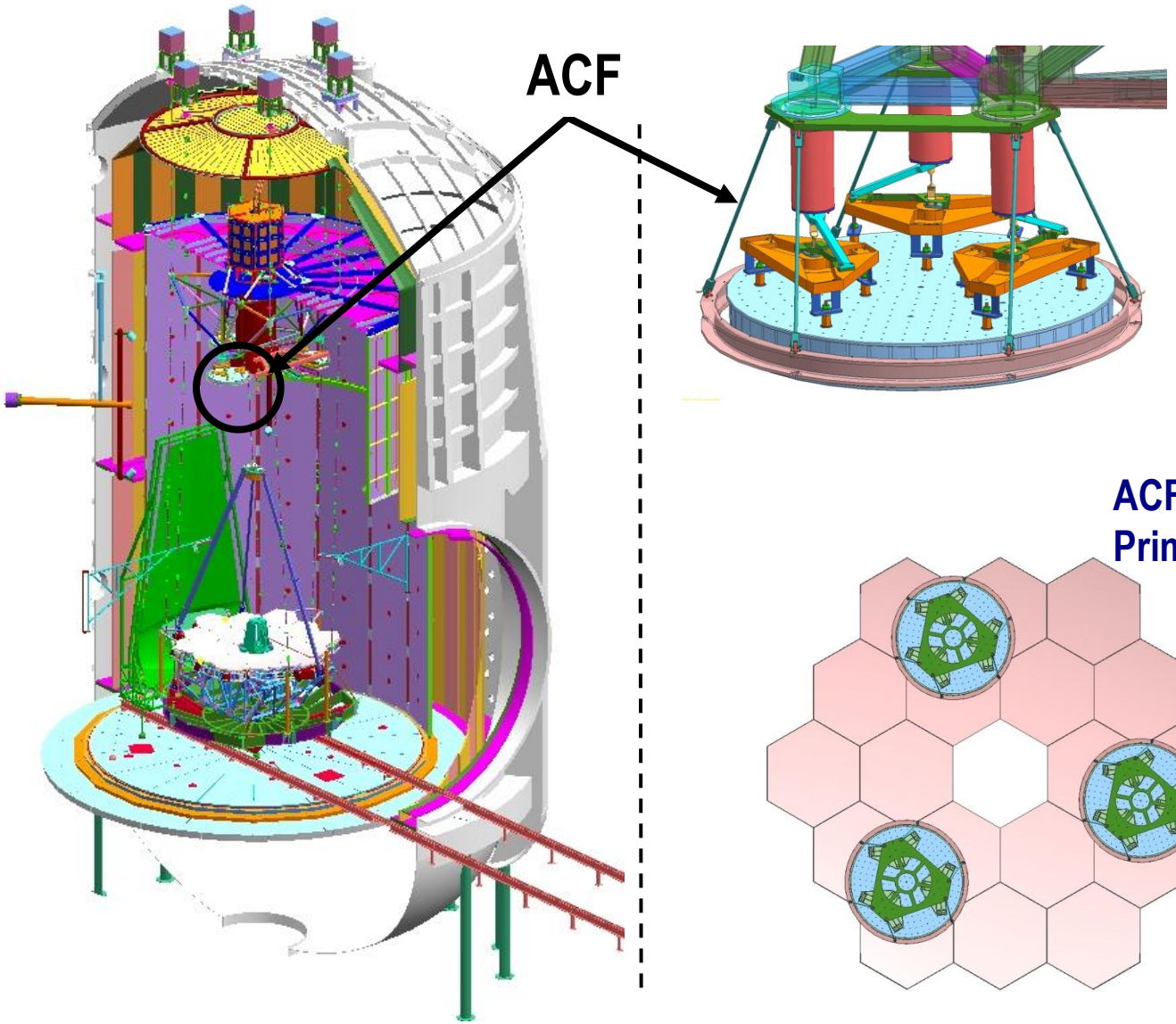
In-Process Testing For Cryo-Figuring 1.5 meter Diameter Auto-Collimating Flats

June 7, 2010

presented by

David J. Fischer, Ph.D.
ITT Geospatial Systems

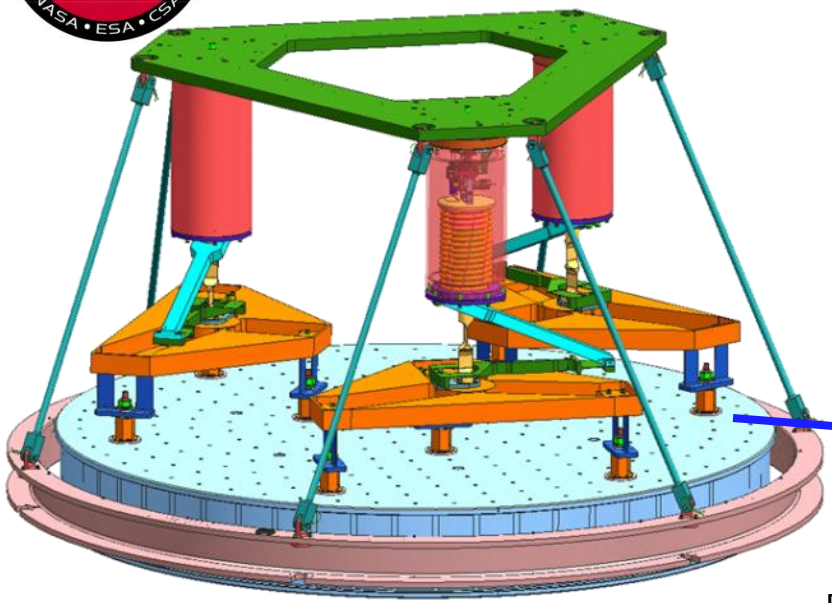
3 Autocollimating Flats used in Cryo-Optical Test of JWST

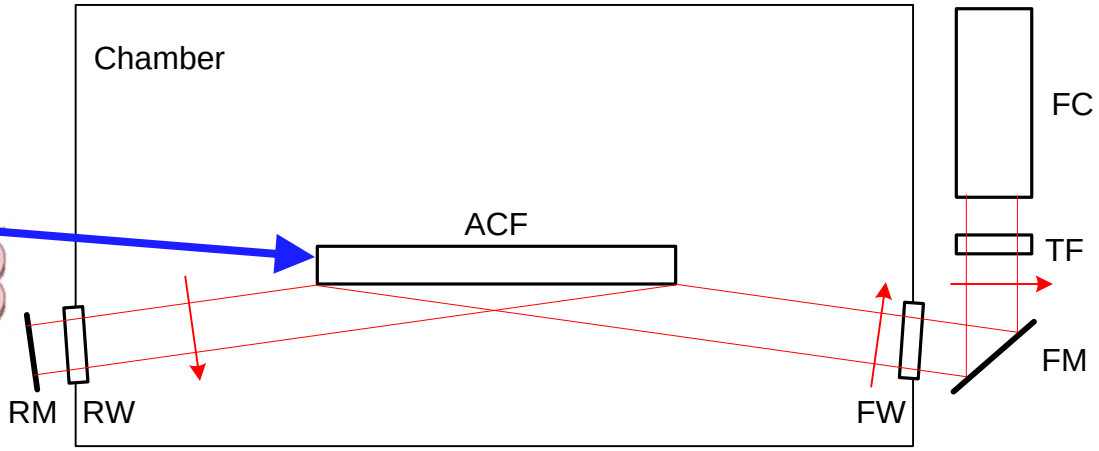


ACF Footprint on Primary Mirror

22 CFR 125.4(b)(13) Applicable

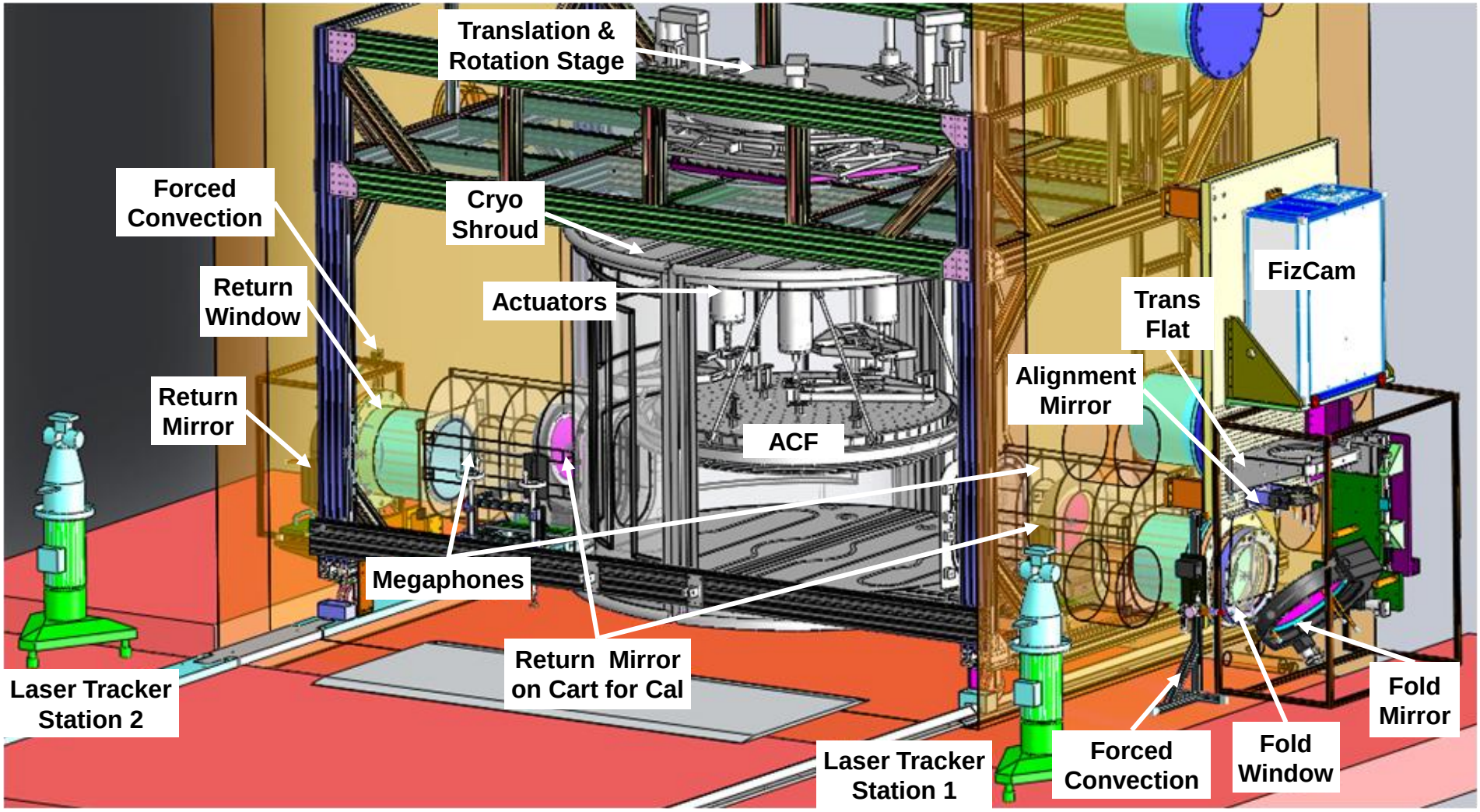
Skip Test Used for Cryo-Figuring ACFs





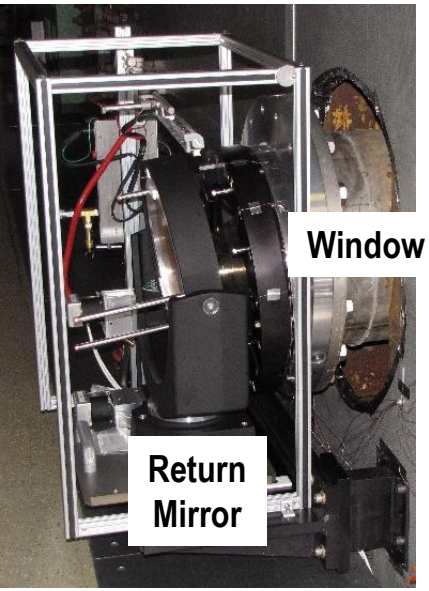
- **Cryo-Vac Skip Test for 32.8 K ACF**
  - 300 mm beam (λ=660 nm) “skips” across ACF diameter at 8.213°
  - 60 sub-aperture Slices at 6° rotations measure entire surface
  - Cryo Backout computed, applied to slice
  - Slices stitched together compute surface map
- **Requirements**
  - Clear Aperture of 1.520 m
  - 75 nm surface rms (including test uncertainty)
  - Uncertainty requirements on power and astigmatism

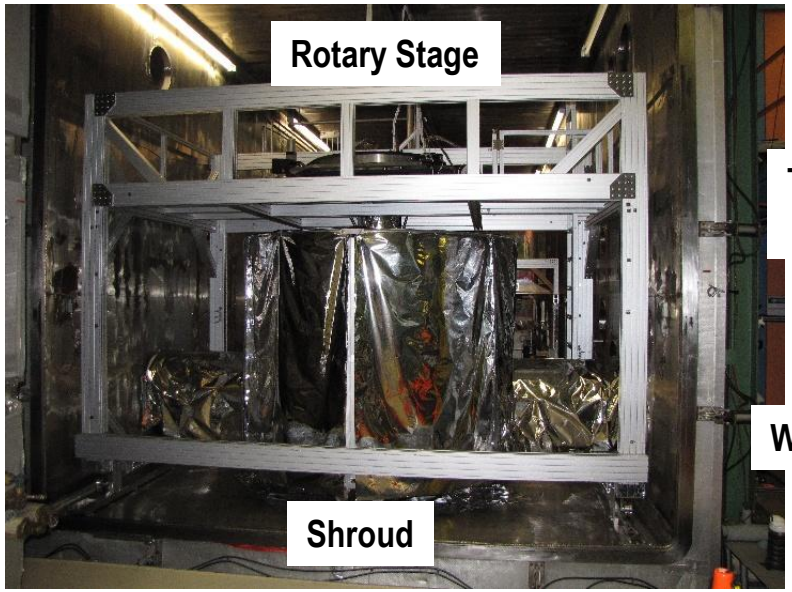
CAD Model of Skip Test

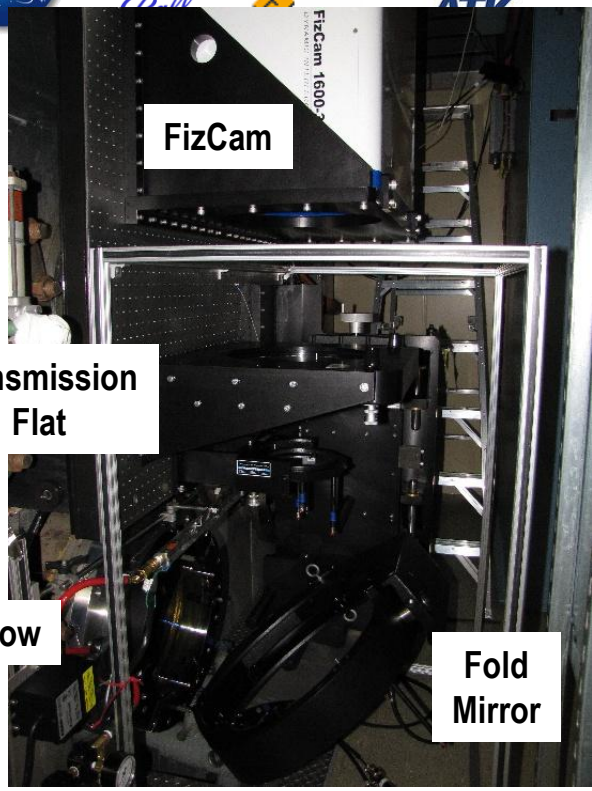


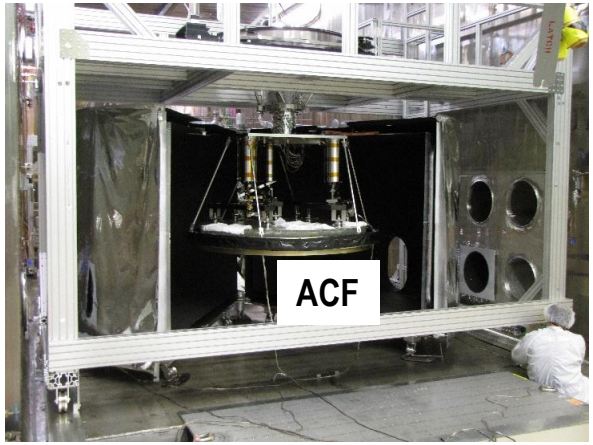
22 CFR 125.4(b)(13) Applicable

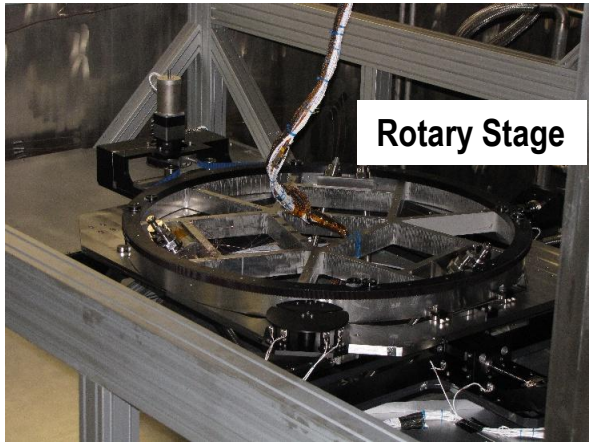
Photographs of Skip Test Hardware







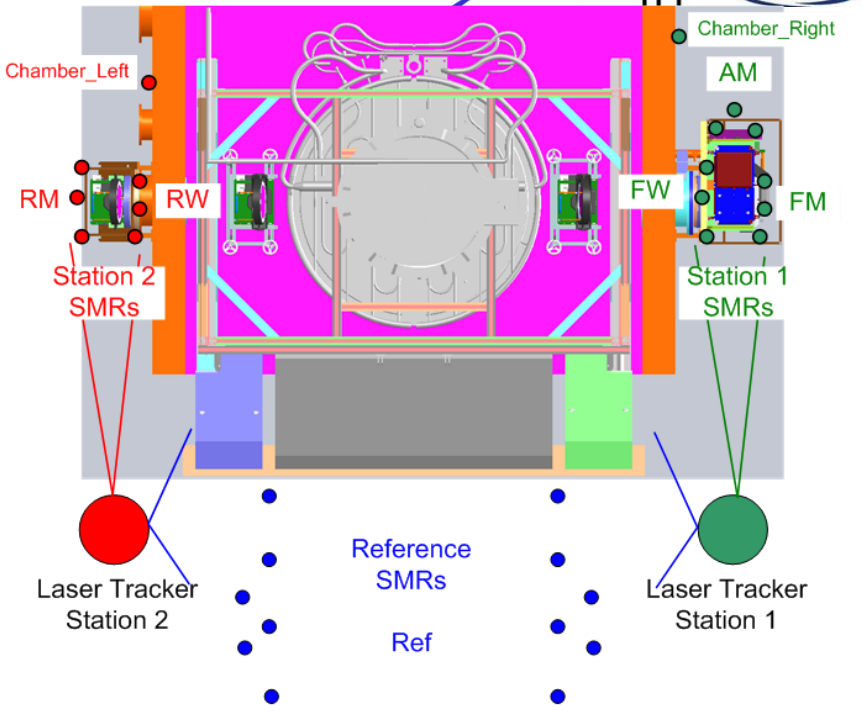


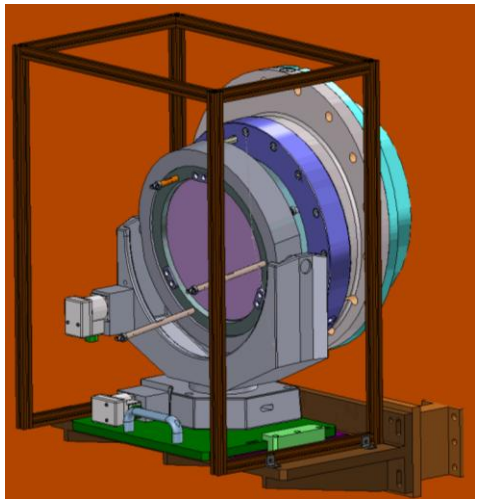


22 CFR 125.4(b)(13) Applicable

Initial Alignment of Test Set by Laser Tracker

- **Align FizCam Transmission Flat and Alignment Mirror (AM)**
- **Initial alignment by Laser Tracker**
  - Align Return Mirror (RM)
  - Coarse align Fold Mirror (FM)
- **RM aligned 1 arcmin (0.017°) accuracy per Theodolite**
- **Laser Tracker shows ACF bias of 12 arcmin (0.2°)**

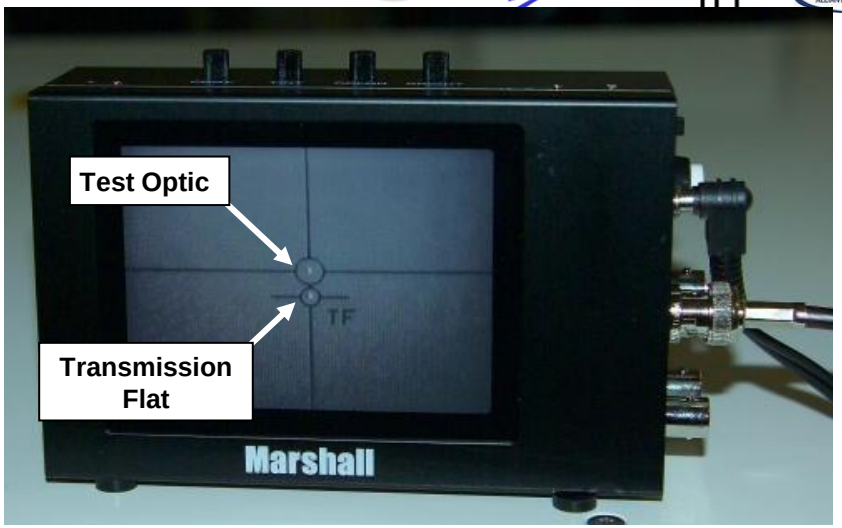


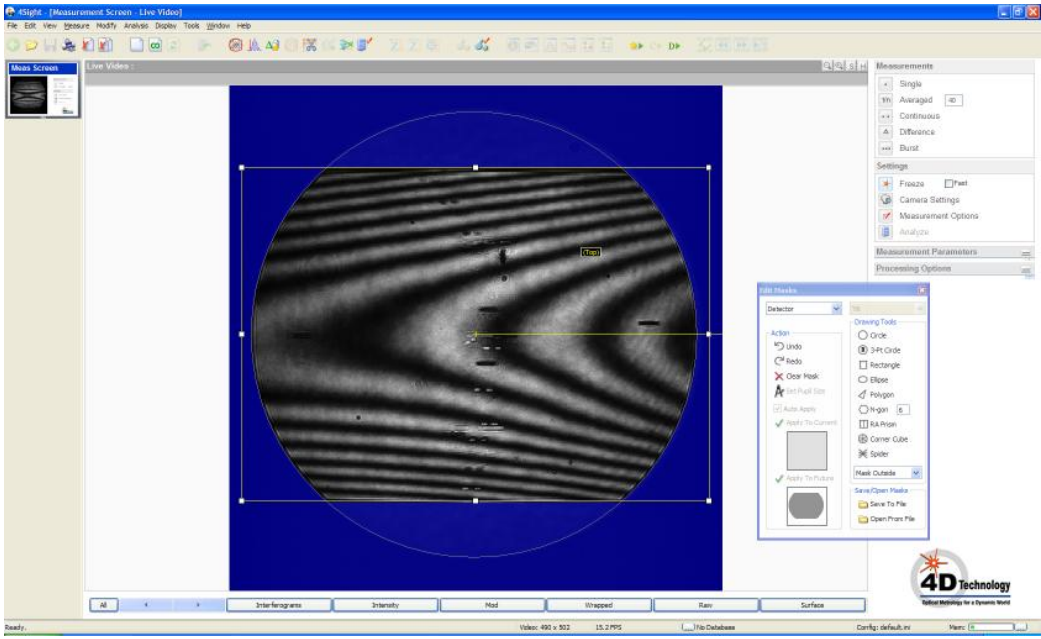


22 CFR 125.4(b)(13) Applicable

Optical Alignment by FizCam

- Align FizCam's Transmission Flat
- Align Return Mirror by Laser Tracker
- Align FM by Alignment Monitor
- Null fringes with FM
- Adjust ACF centration by live video

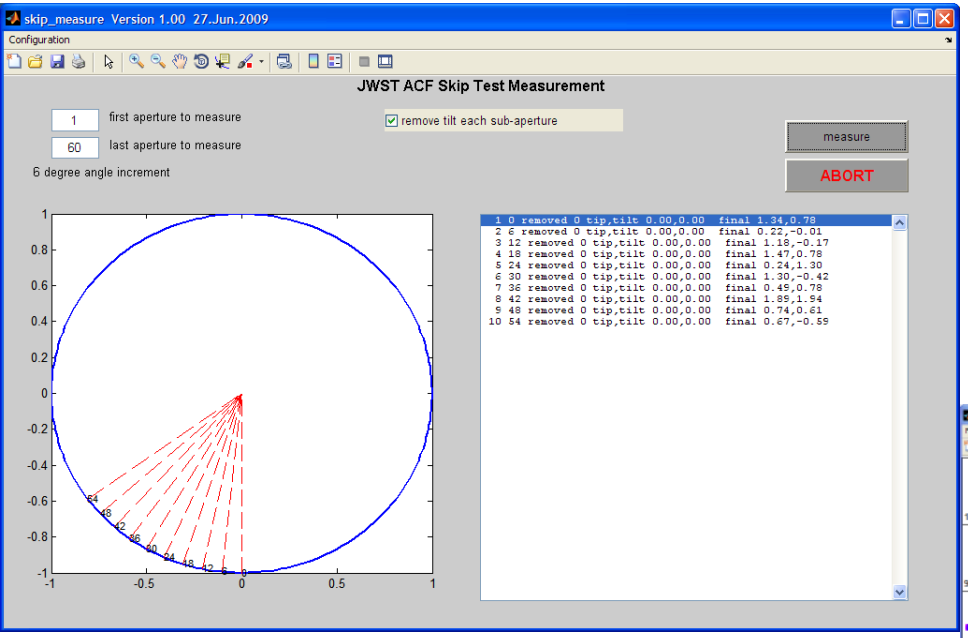




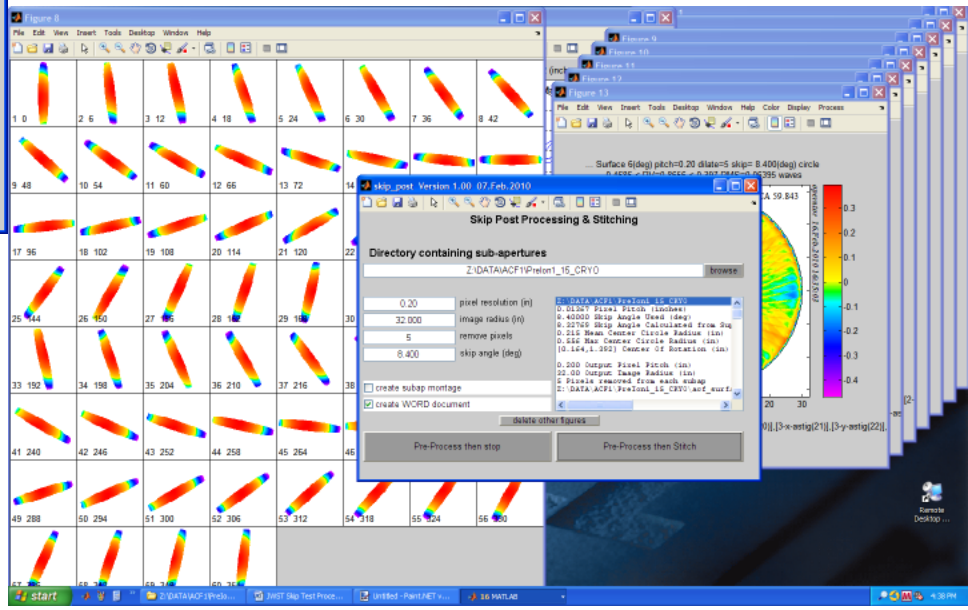
22 CFR 125.4(b)(13) Applicable

Automated Measurement & Analysis Make Complex Test Simpler

Stitching software rotates, de-tilts, and measures for 360° rotation



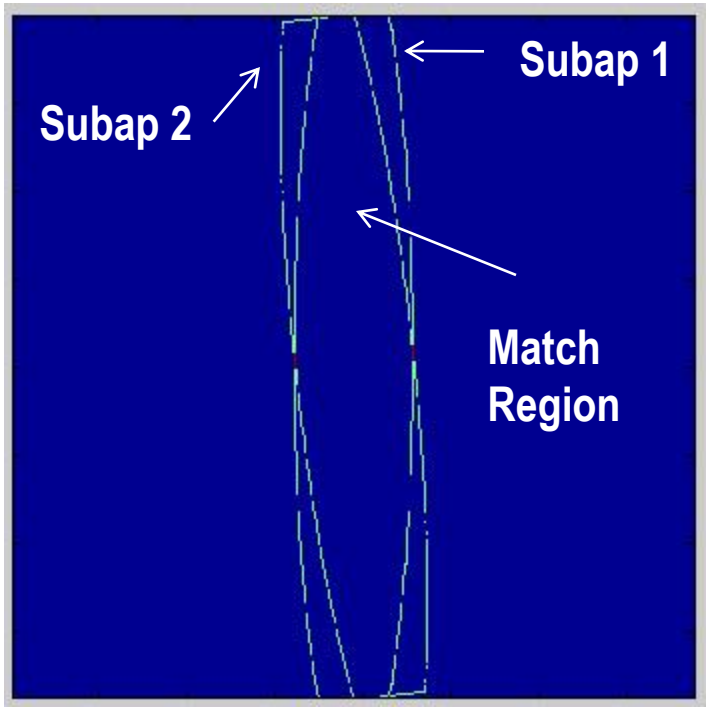
Stitching processes 360° measurement with summary report

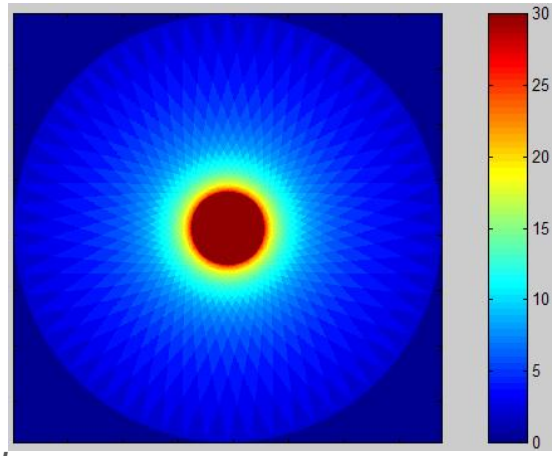


22 CFR 125.4(b)(13) Applicable

Description of Stitching Approach

1. Interferograms Scaled, Stretched and Rotated by Nominal Geometry
2. 1st Subap is Reference for Scale
3. Nth Subap Matched to N-1th Subap in data overlap region & replaced with Match. Matching done by fitting tilt & scale
4. Final Map is Sum of Adjusted Subaps, normalized Pixel-by-Pixel using Sub-Ap Pixel Map

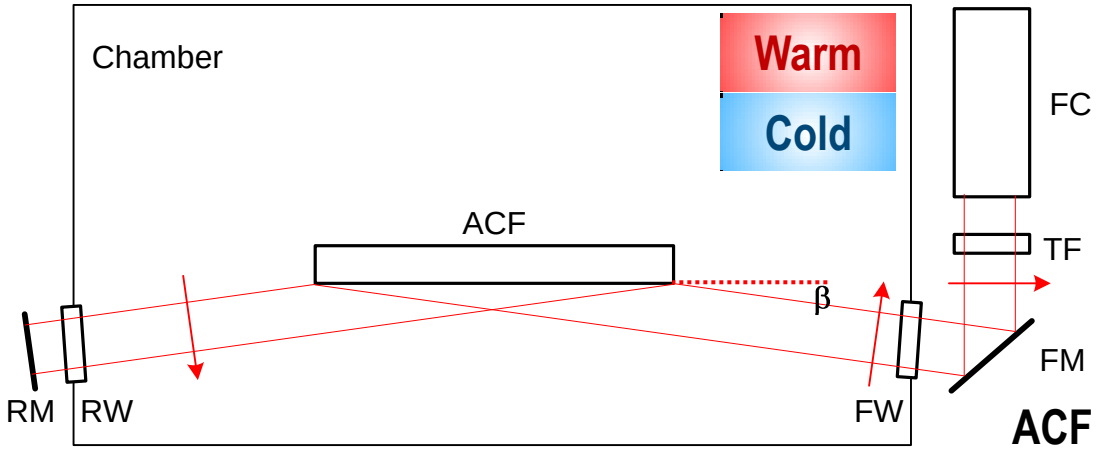


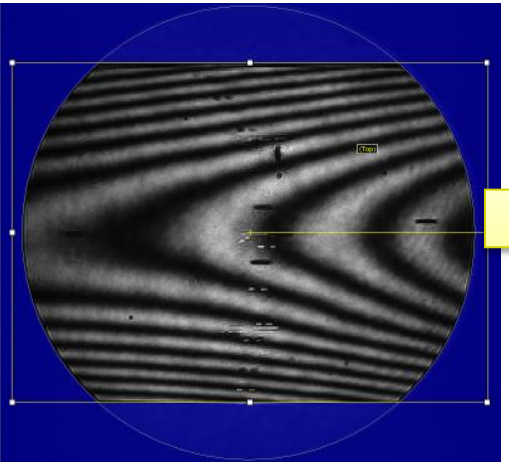


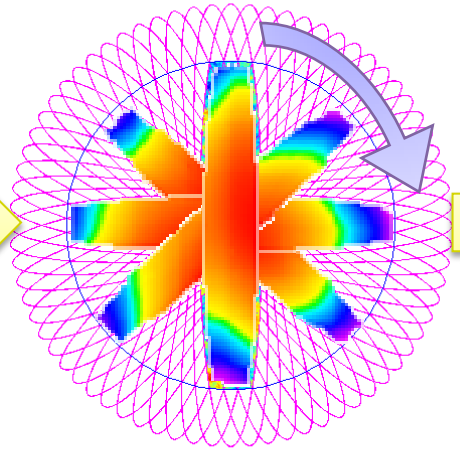
Sub-Ap Pixel Map

Variations on : Otsubo M. et al,"Measurement of large plane surface …", Opt. Engineering 33, 608-613 (1994).

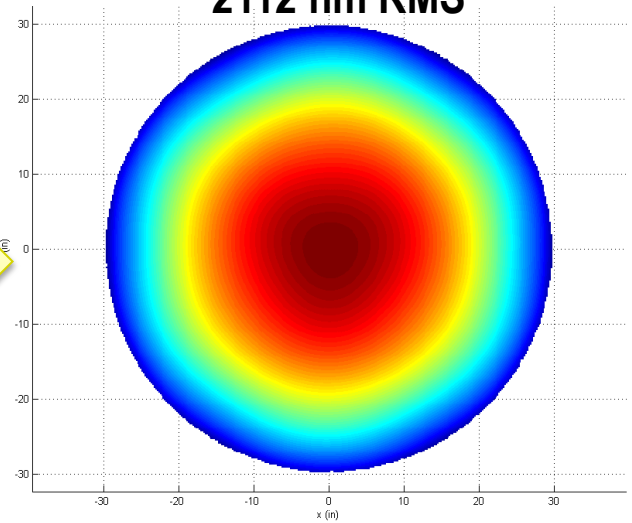
ACF Surface Computed by Stitching 60 Slices (6° Rotations)







ACF Surface at 32.8 K
2112 nm RMS



$$W_{M,n} = 2FC + 2TF + 4FM + 2FW + 2RW + 2RM + 4\sin\left(\frac{\beta}{2}\right)ACF_n$$

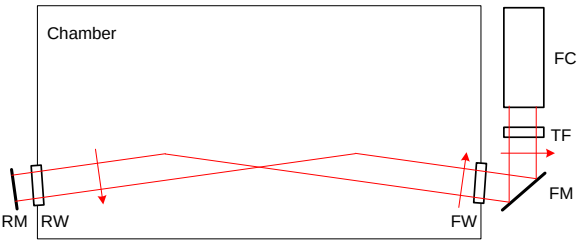
22 CFR 125.4(b)(13) Applicable

Cryo Backout: Test Set + Cryo-Delta

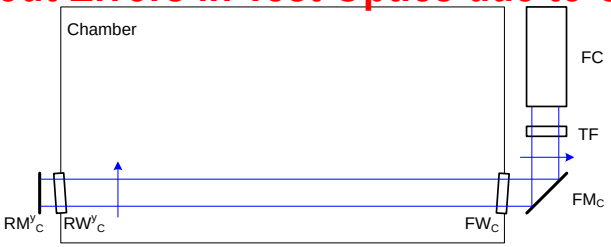
$$W_B = W_T\big|_{WARM} + \frac{1}{2}\left[\left(W_C + W_C^y\right) + \left(W_M - W_M^y\right)\right]_{CRYO} - \frac{1}{2}\left[\left(W_C + W_C^y\right) + \left(W_M - W_M^y\right)\right]_{WARM}$$

Backout Errors in Test Optics at Warm-Vac

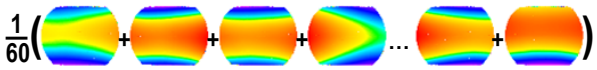
Backout Errors in Test Optics due to Cryo Shift



W_T

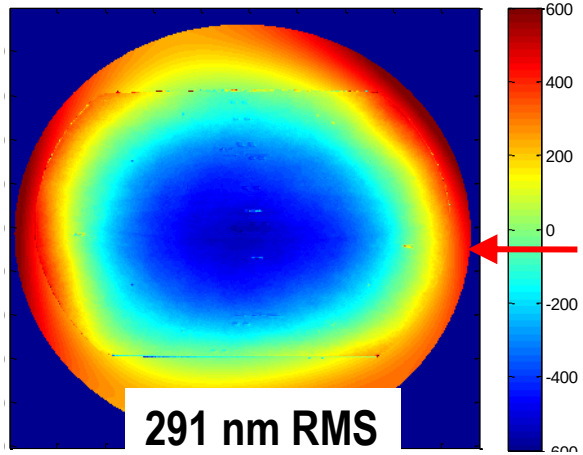


W_C



W_M

$W_B =$

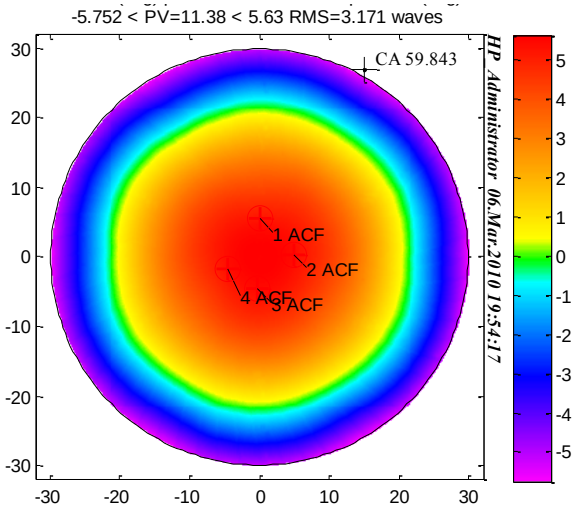


Subtract Extrapolated Backout from each Slice before Stitching

Gradient Reconstruction
Backout not used

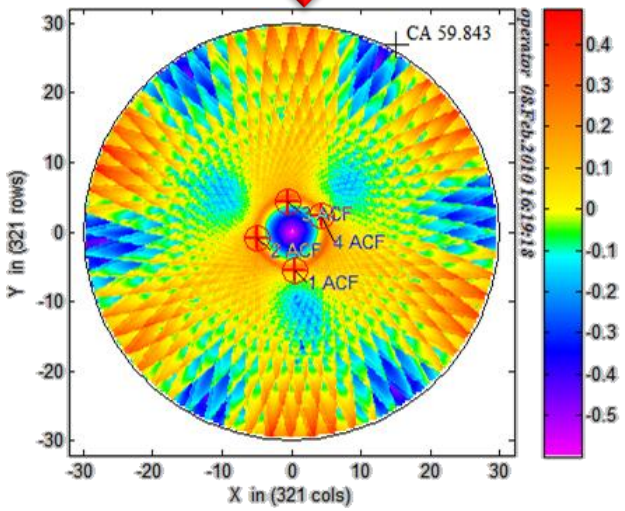
Backout Improves Stitching Results

No Backout
Clear Stitching Artifacts
Higher Surface Residual

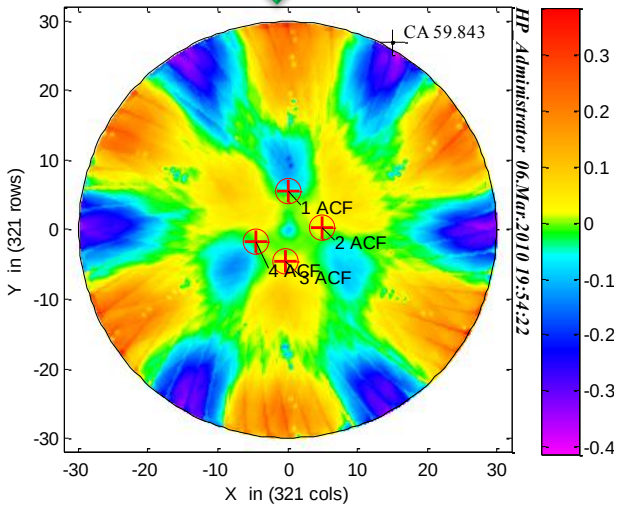


ACF Surface at 32.8 K
2112 nm RMS

Use Cryo Backout
Smoother Surface
Smaller Surface Residual



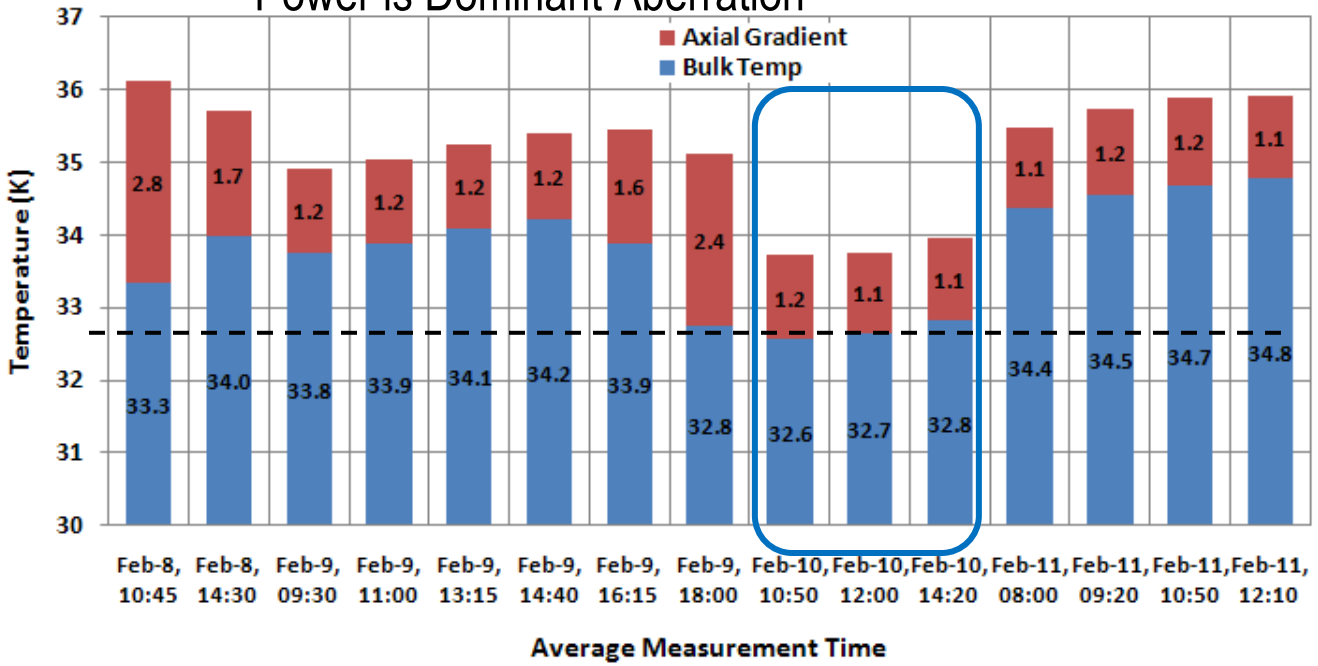
37-Zernike Fit Residual
95 nm RMS



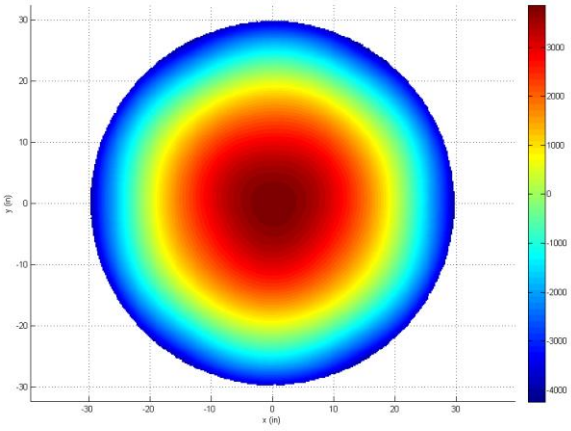
37-Zernike Fit Residual
77 nm RMS

Cryo Testing Successful

- **Pre-Ion 1 Skip Test Complete**
- **Warm Vac**
  - Figure agrees with OAGM Probe
- **Cryo-Vac (32.8 K)**
  - Hitmap: 3 Surface Maps from Feb 10
  - Close to Warm Vac
  - Power is Dominant Aberration



ACF Surface at 32.8 K
2112 nm RMS

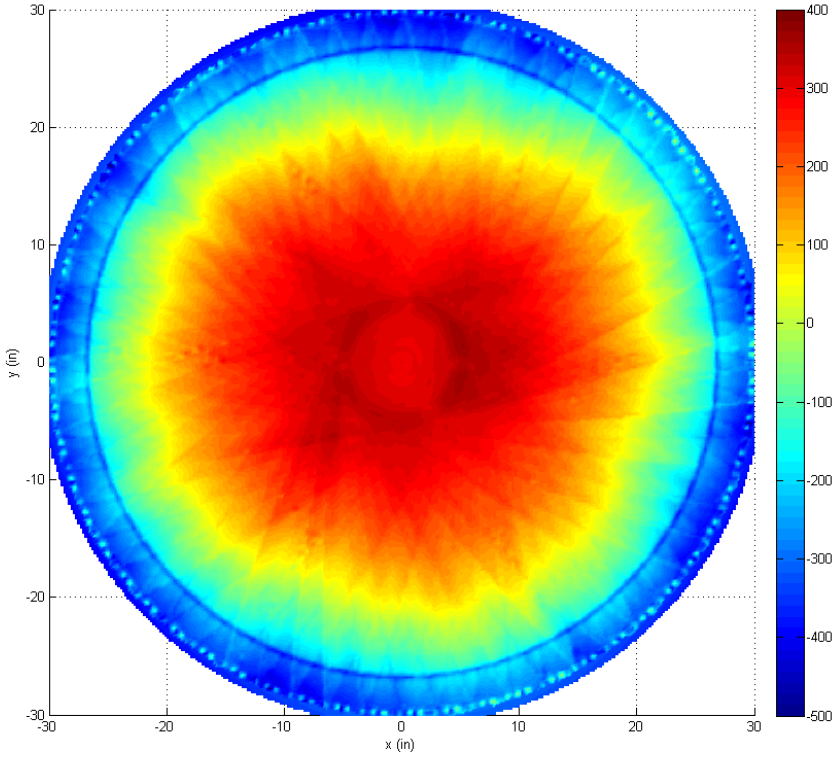


22 CFR 125.4(b)(13) Applicable

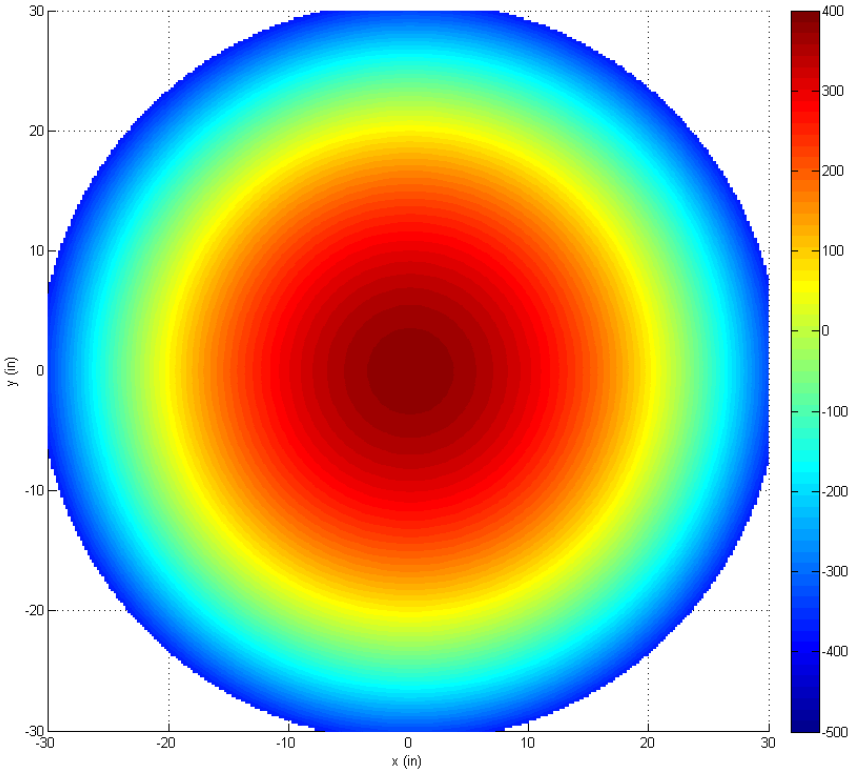
Cryo Shift Successfully Measured

- **Cryo Shift is 224 nm RMS**
  - Power and Stitching Errors
  - Relatively low compared to worst-case predictions of 3000 nm RMS
- **ACF2 & ACF3 to benefit from thermal facility improvements**

ACF1 Cryo Shift
224 nm RMS



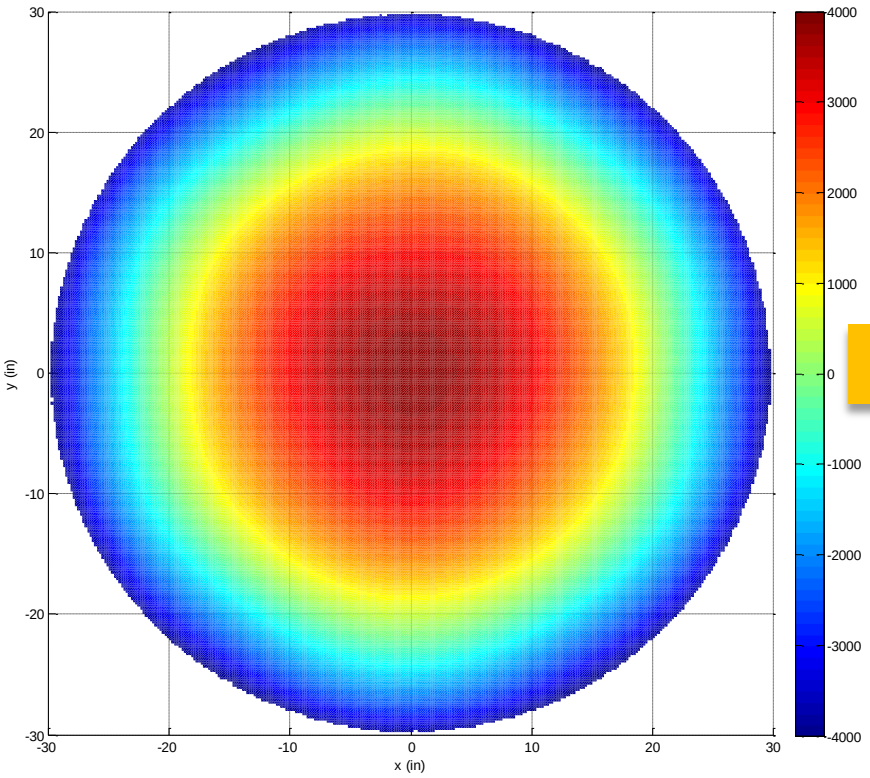
Power in Cryo Shift
220 nm RMS



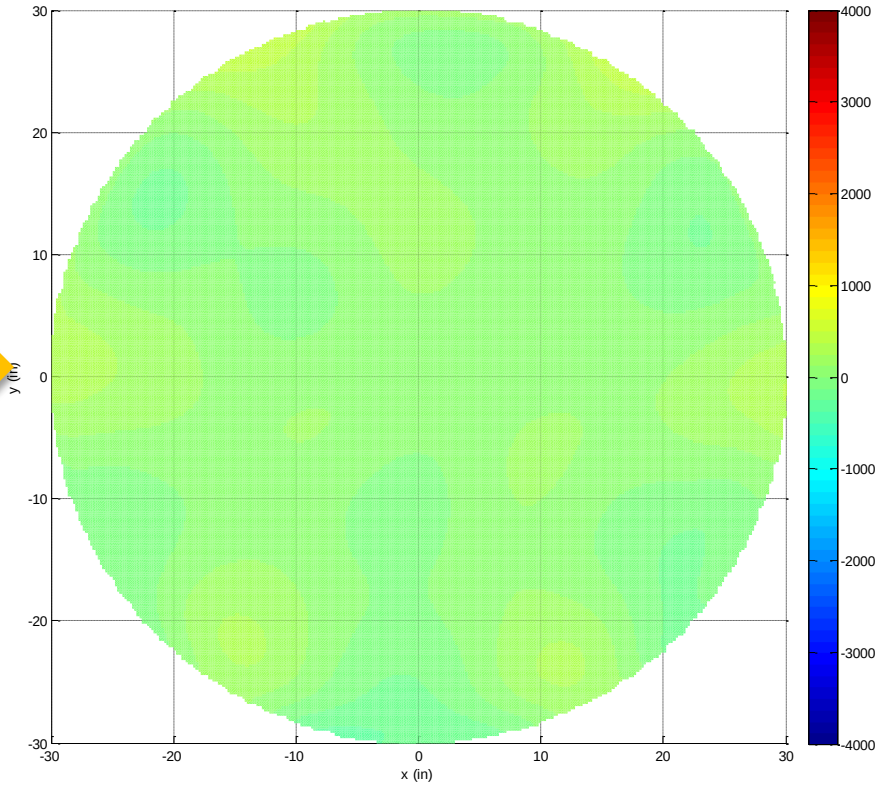
22 CFR 125.4(b)(13) Applicable

Cryo Surface Progress

Initial Surface
2184 nm RMS



Current Hitmap
108 nm RMS



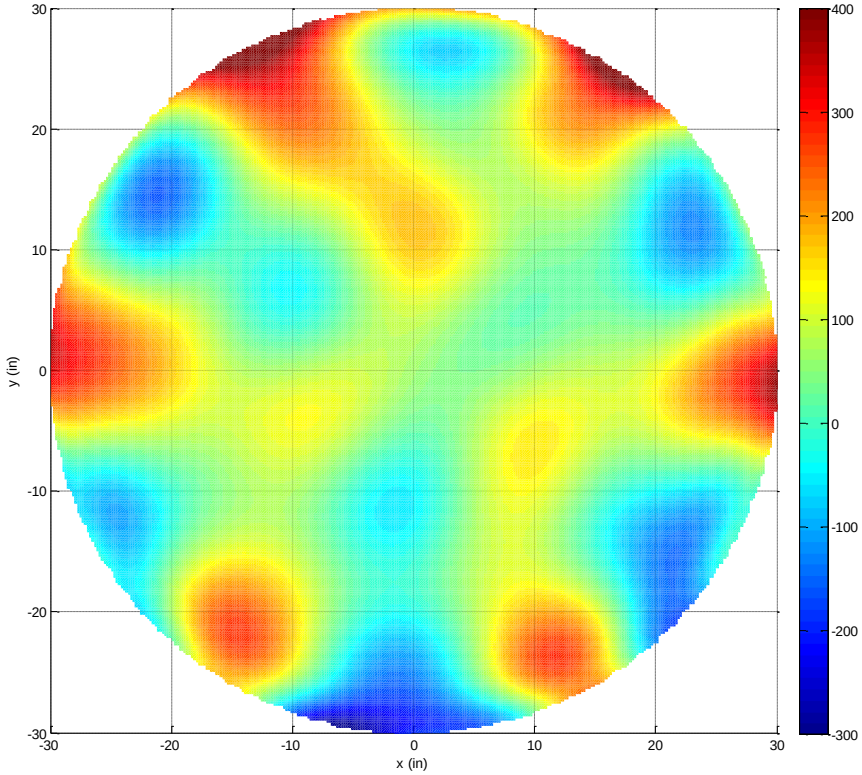
Stitching Artifacts Removed for Hitmap

22 CFR 125.4(b)(13) Applicable

Summary: ACF1 Nearing Completion

- **ACF Skip Test Fully Functional**
  - Multiple Cryo-Vac Measurements at 32.8 K
  - Multiple Warm-Vac Measurements
  - Complete Backout Measured and Computed for Warm and Cryo
  - Cryo-Shift Computed & Found to be Small
- **ACF #1 Nearing Completion**
  - Final Ion Hit Beginning
  - Final Warm-Vac & Cryo-Vac Testing Planned

Current Hitmap
108 nm RMS



22 CFR 125.4(b)(13) Applicable